

UNITED STATES AIR FORCE RESEARCH LABORATORY

RISK ASSESSMENT FOR PHOSPHORUS TRIBROMIDE

D.R. Mattie

OPERATIONAL TOXICOLOGY BRANCH
HUMAN EFFECTIVENESS DIRECTORATE
2856 G STREET, BLDG 79
WRIGHT-PATTERSON AFB, OH 45433-7400

P.D. Haaland

HUNTINGTON RESEARCH AND ENGINEERING
PO BOX 90118
SAN JOSE, CA 95109

T.R. Sterner

OPERATIONAL TECHNOLOGIES CORP.
1370 NORTH FAIRFIELD ROAD, SUITE A
BEAVERCREEK, OH 45432

R.E. Wolfe

D.E. Dodd

MANTECH-GEO CENTERS JOINT VENTURE
PO BOX 31009
DAYTON, OH 45437-0009

December 1998

Interim Report - October 1996 - March 1997

20001117 010

Human Effectiveness Directorate
Deployment and Sustainment Division
Operational Toxicology Branch
2856 G Street
Wright-Patterson AFB OH 45433-7400

Approved for public release; distribution is unlimited.

NOTICES

When US Government drawings, specifications or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Air Force Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies and their contractors registered with the Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Service
8725 John J. Kingman Rd., Ste 0944
Ft. Belvoir, Virginia 22060-6218

DISCLAIMER

This Technical Report is published as received and has not been edited by the Technical Editing Staff of the Air Force Research Laboratory.

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-1998-0132

The animal use described in this study was conducted in accordance with the principles stated in the "Guide for the Care and Use of Laboratory Animals", National Research Council, 1996, and the Animal Welfare Act of 1966, as amended.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR



STEPHEN R. CHANNEL, Maj, USAF, BSC
Branch Chief, Operational Toxicology Branch
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 1998		3. REPORT TYPE AND DATES COVERED Interim Report - October 1996-March 1997
4. TITLE AND SUBTITLE Risk Assessment for Phosphorus Tribromide			5. FUNDING NUMBERS Contract F41624-96-C-9010 PE 62202F PR 7757 TA 7757A1 WU 7757A102	
6. AUTHOR(S) Mattie, D.R., Haaland, P.D., Sterner, T.R., Wolfe, R.E., and Dodd, D.E.				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) ManTech Geo-Centers Joint Venture PO Box 31009 Dayton, OH 45437-0009			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Human Effectiveness Directorate Air Force Research Laboratory Wright-Patterson AFB, OH 45433-7400			10. SPONSORING/MONITORING AGENCY REPORT NUMBER AFRL-HE-WP-TR-1998-0132	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Phosphorus tribromide (PBr3) has effective fire fighting properties which make it a possible replacement for Halon 1301. Results of genotoxicity testing using bacterial Salmonella strains indicted PBr3 is not a mutagen for either frame shift or base-pair substitution tester strains in both buffered and unbuffered solutions. Acute aquatic toxicity testing determined a 96-hour LC50 value for fathead minnows at 71 mg/L (25 mg/L NOEC) and a 48-hour EC50 value for <i>Daphnia magna</i> at 22.6 mg/L (6.25 mg/L NOEC). Application of 10 ul neat PBr3 to intact skin of an anesthetized NZW rabbit caused edema and necrosis of the treated skin within 10 minutes of dosing. Toxicity was not observed in rats exposed for 4 hr to 0.4 mg/L in an inhalation exposure. Male rats (5/group) were exposed to PBr3 vapor, 4 hr/d for 5d, at 0, 0.06, 0.16 and 0.51 mg/L PBr3; 0.06 mg/L was the NOAEL. Rats (10/sex/group) were exposed to PBr3 vapor, 4 hr/d, 5 d/wk, for 4 wk at 0, 0.03, 0.01 and 0.3 mg/L; the NOAEL was 0.1 mg/L. Phosphorus tribromide reacts with moisture in the air to produce phosphonic acid and hydrogen bromide gas (HBr). A 10 cc cartridge of PBr3, tested as fire suppressant, would react to form an estimated 25 g of HBr. If uniformly distributed in a room 10x10x5 m in size, the maximum HBr concentration would be 0.05 mg/L (50 mg/m3); if in a 61.5x46.2x14.8 m hanger, it would be 5.9x10-4 mg/L (0.59 mg/m3). Since the exposure limit for HBr is 10 mg/m3, the maximal hanger concentration would be below the action level, indicating that an acceptable exposure level during usage on aircraft is possible based on the physical characteristics of PBr3 and the small amount necessary for fire suppression. Dermal and eye contact with PBr3 should be avoided due to its corrosive behavior.				
14. SUBJECT TERMS Phosphorus tribromide Hydrogen bromide			15. NUMBER OF PAGES 21	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

THIS PAGE INTENTIONALLY LEFT BLANK

PREFACE

This is one of a series of technical reports describing a preliminary risk assessment for phosphorus tribromide tested at the Operational Toxicology Branch under the ManTech Geo-Centers Joint Venture contract. This document serves as a final report for the project conducted for phosphorus tribromide as a potential Halon replacement. The research described in this report began in October 1996 and was completed in March 1997 under Department of Defense Contract No. F41624-96-C-9010. Lt. Col Terry A. Childress, served as Contract Technical Monitor for the U.S. Air Force, Armstrong Laboratory. This study was sponsored by WL/MLBT.

The animal use described in these studies was conducted in accordance with the principles stated in the "Guide for the Care and Use of Laboratory Animals", National Research Council, 1996, and the Animal Welfare Act of 1966, as amended.

TABLE OF CONTENTS

SECTION	PAGE
PREFACE	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	v
ABBREVIATIONS	vi
HAZARD ASSESSMENT	1
EXPOSURE ASSESSMENT	6
RISK CHARACTERIZATION	11
CONCLUSIONS	13
REFERENCES	14

LIST OF FIGURES

FIGURES	PAGE
1	Milligrams of PBr_3 versus time in an open weigh boat with moderate ventilation at room temperature7

ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
BTU/hr	British thermal units per hour
°C	Degrees centigrade
CaCO ₃	Calcium carbonate
cc	Cubic centimeter
cm ²	Square centimeter
cm ² /s	Square centimeter per second
cm ³	Cubic centimeter
DoD	Department of Defense
EC ₅₀	Median effective concentration
F-344	Fischer 344 (rats)
ft	Feet
g	Grams
g/cm ³	Grams per cubic centimeter
H ₂ O	Water
HBr	Hydrogen bromide
H ₃ PO ₃	Phosphonic acid
LC ₅₀	Median lethal concentration
m ³	Cubic meter
mg/m ³	Milligrams per cubic meter
mg/L	milligrams per liter
mL	Milliliter
NIOSH	National Institute for Occupational Safety and Health
NOAEL	No-observable-adverse-effect-level
NOEC	No Effect Concentration
NZW	New Zealand White (rabbits)
OSHA	Occupational Safety and Health Administration
PBr ₃	Phosphorus tribromide
PEL	Permissible exposure limit
ppb	Parts per billion
ppm	Parts per million
RH	Relative humidity
TLV	Threshold limit value
TWA	Time-weighted average
ug/cm ² s	Microgram per square centimeter seconds
ug/L	Microgram per liter
uL	Microliter
U.S.	United States

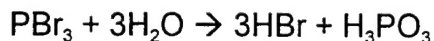
SECTION I

HAZARD ASSESSMENT

Phosphorus tribromide (PBr_3) has effective fire fighting properties which make it a possible replacement for Halon 1301. The DoD requires the development of a toxicity profile for replacement candidates of Halons, which includes the results from acute and subchronic toxicity testing. Many potential replacements, including phosphorus tribromide, have not been thoroughly investigated to determine their toxicological properties. The purpose of this report is to summarize the toxicity studies conducted for phosphorus tribromide and to conduct a preliminary risk assessment for this compound. The risk assessment will help determine if phosphorus tribromide (PBr_3) can be used as a Halon replacement compound.

Tests in a 500,000 BTU/hr test burner demonstrated that PBr_3 is an effective fire extinguishant. The test burner was quenched by only 0.2 mL PBr_3 . This volume is several thousand times less than the amounts required of other Halon replacements to suppress fires. New fire extinguishant systems utilizing PBr_3 would occupy less volume, weigh less and require less mechanics than current systems. Also, PBr_3 has no ozone depleting potential since it is rapidly hydrolyzed in the troposphere.

Phosphorus tribromide reacts with moisture in the air and on wet surfaces to produce phosphonic acid and hydrogen bromide gas (HBr) according to the following reaction:



There is limited toxicity information available in the literature for phosphorus tribromide and hydrogen bromide. No acute toxicity information is available for phosphonic acid or hydrobromic acid, the aqueous form of HBr. The combined interaction of these compounds to cause potential health hazards is not known.

In a study of rats exposed to 1300 ppm HBr for 30 minutes, nose-breathing effects were compared to pseudo-mouth-breathing effects. Tissue injury in the nasal region of the respiratory tract was observed, including epithelial and submucosal necrosis. Pseudo-mouth-breathing exposure to HBr caused higher mortality rates and major tissue disruption in the trachea. Observations of the trachea included necrosis of the epithelium, submucosa, glandular tissue and cartilage (Stavert *et al.*, 1991). In a separate study, the rat LC₅₀ for one hour was 2858 ppm while the mouse LC₅₀ for one hour was 814 ppm (RTECS, 1995a).

Human inhalation of 1300 to 2000 ppm HBr over a period of minutes was reported to be lethal (HSDB, 1995a). A short exposure to 35 ppm caused throat irritation (HSDB, 1995b), while exposure to 5 and 6 ppm for several minutes by 6 human volunteers also resulted in nose (6 out of 6) and throat irritation (1 out of 6) without eye discomfort (6 out of 6) (ACGIH, 1991a; HSDB, 1995c).

An accidental human exposure to PBr₃ and HBr was reported by Kraut and Lilis (1988). While mixing PBr₃, a female laboratory assistant was exposed to PBr₃ and HBr via splashing on the face, chest and hair, and by inhalation of

resulting vapors. She remained in the area of the exposure for five to ten minutes. Immediate effects noted were complaint of dry cough, light-headedness and slight congestion of the throat. Over the next two weeks, the subject experienced increasing shortness of breath. Chest x-rays revealed bilateral lobe infiltrates resulting in a diagnosis of chemical pneumonitis. She was allowed to return to work a few months later, though dyspnea on exertion persisted and chest x-ray findings had not yet completely resolved. Recovery was slowed by a number of relapses, apparently due to exposure to other respiratory irritants (Kraut and Lilis, 1988). No exposure assessment was conducted and attempts to get exposure information were not successful.

Results of genotoxicity testing of bacterial *Salmonella* strains indicated PBr_3 is not a mutagen. These results were consistent for frame shift and base-pair substitution tester strains in both buffered and unbuffered solutions (ManTech, 1996).

No ecological dose-response levels were reported for HBr. Acute aquatic toxicity tests on fathead minnows (*Pimephales promelas*) and *Daphnia magna* were recently conducted with Pbr_3 . Fathead minnows (10 per group) were exposed to 0.0, 6.25, 12.5, 25.0, 50.0 or 100.0 mg/L PBr_3 in fresh water (88 mg/L hardness as CaCO_3) at 22 ± 2 °C. The static tests were performed in replicate and the results were pooled. The 96-hour LC_{50} value for fathead minnow was 71 mg/L (50 - 100 mg/L confidence limit); the no observed effect concentration (NOEC) was 25 mg/L (Aqua Survey, 1996a). These results indicate that an

isolated or intermittent exposure to a concentration of PBr_3 equal to 71 mg/L, is likely to cause death to 50 percent of fathead minnows, *Pimephales promelas*. A concentration equal to or less than 25 mg/L is not likely to have an adverse effect. *Daphnia* (10 per group) were exposed to 0.0, 6.25, 12.5, 25.0, 50.0 or 100.0 mg/L PBr_3 in fresh water (88 mg/L hardness as CaCO_3) at 20 ± 2 °C. The static tests were performed in replicate and the results were pooled. The 48-hour EC_{50} value for *Daphnia magna* was 22.6 mg/L (18.2 - 27.9 mg/L confidence limit); the NOEC was 6.25 mg/L (Aqua Survey, 1996b). These results indicate that an isolated or intermittent exposure to a concentration of PBr_3 equal to 22.6 mg/L is likely to cause mortality/immobilization to 50 percent of the Cladoceran *Daphnia magna*, while a concentration equal to or less than 6.25 mg/L is unlikely to have an adverse effect.

Acute and subchronic PBr_3 studies were designed to determine the effects following single, high-concentration exposures which could occur in accidents, as well as repeated, low-concentration exposures which could occur on flight lines or during maintenance. Application of 10 or 50 μL neat PBr_3 to intact skin of an anesthetized NZW rabbit caused edema and necrosis of the treated skin within 10 minutes of dosing. Microscopic examination confirmed necrosis of the skin and underlying areas, including skeletal muscle of the subcutis. Application of 10 or 50 μL neat PBr_3 to intact skin of an anesthetized NZW rabbit for 30 seconds followed by a one minute water wash resulted in necrosis of the entire skin, but not the underlying skeletal muscle. An acute 4-hour nose-only

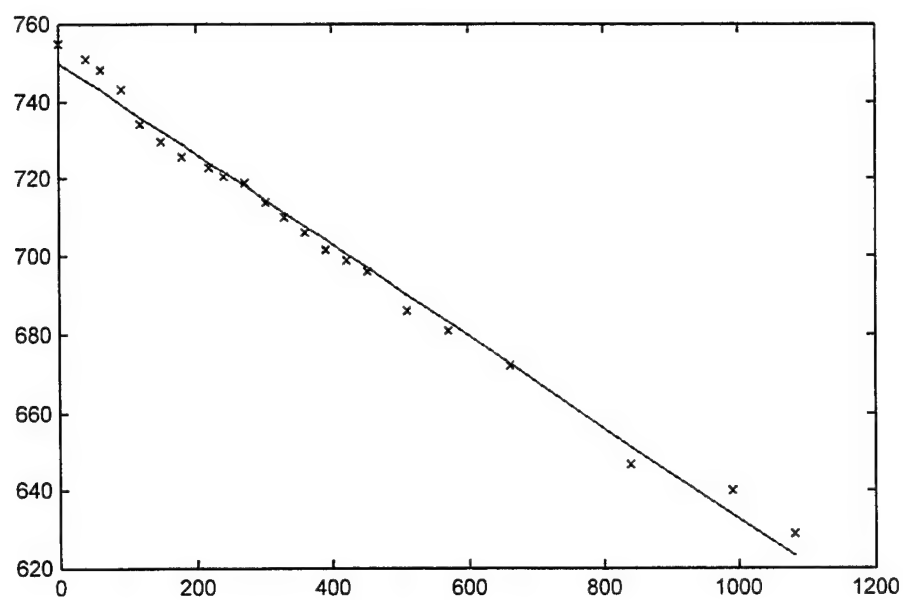
exposure of Fischer 344 rats to PBr_3 vapor resulted in mortality at 4.1 mg/L. At 1.5 mg/L, labored breathing, body weight loss, ulceration of anterior nares and rhinitis of the nasal passage were observed. Adverse effects were not observed in rats exposed for 4-hour to 0.4 mg/L. Male rats (5 per group) were exposed to PBr_3 vapor, 4 hours/day for 5 days, at 0, 0.06, 0.16 and 0.51 mg/L PBr_3 . There were no signs of adverse effects at the low and mid-exposure levels. Rats in the 0.51 mg/L group had decreased body weights, gross lesions (reddened nares) and microscopic lesions (inflammation of mucosa and ulceration of epithelium in the nares). Rats (10 per sex per group) were exposed to PBr_3 vapor, 4 hours per day, 5 days per week, for 4 weeks at 0, 0.03, 0.1 and 0.3 mg/L. There were no signs of toxic stress, alterations in body weights or changes in organ weights in PBr_3 exposed animals. Minor serum chemistry and hematology effects were observed in the treated animals. Microscopic tissue findings were limited to rats of the 0.3 mg/L group and consisted of mild inflammation of the nasal passages. A concentration of 0.1 mg/L is the no-observable-adverse-effect level (NOAEL) in the 28-day inhalation study (Wolfe *et al.*, 1997).

SECTION II

EXPOSURE ASSESSMENT

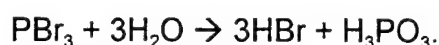
In order to calculate an inhalation exposure for PBr_3 , the following information is needed: vapor pressure (2.25 Torr at 20 °C), molecular weight (270.7), density (2.8 g/cm^3) and evaporation rate of the material as a function of temperature ($7.6 \text{ } \mu\text{g/cm}^2\text{s}$). The evaporation rate was based on an experiment conducted with a puddle of PBr_3 (4.755 g or 1.66 cc) with a surface area was 15.5 cm^2 . The puddle was placed in a moderately ventilated room with a low relative humidity and the mass change was monitored over time at room temperature. Figure 1. shows the evaporation results, which fit a mass transfer (evaporation) rate of 7.6 micrograms per square centimeter per second. While this value may increase a few fold with more vigorous ventilation, it is still four orders of magnitude slower than evaporation into a vacuum. This material (PBr_3) is so dense and its vapor pressure so low that mass transfer becomes dominated by diffusion.

Figure 1. Milligrams of PBr_3 versus time in an open weigh boat with moderate ventilation at room temperature.



These numbers can be used to estimate the rate at which PBr_3 is released following a spill or accidental discharge. The density of PBr_3 is greater than aluminum; a spray, stream or aerosol will settle rapidly on the floor in the event of an accidental release.

After evaporation into the air, the material would react rapidly with atmospheric moisture to form HBr and H_3PO_3 , according to the reaction:



The hydrolysis rate for this reaction is $4 \times 10^{-17} \text{ cm}^2/\text{s}$. This hydrolysis rate is based on the amount of water in air in molecules per cubic centimeter. At room temperature this quantity is expressed as the product of the relative humidity and the saturated vapor pressure of water (17.5 torr or 6.18 molecules per cubic centimeter). At 50% relative humidity (RH), the hydrolysis lifetime is 81 milliseconds. At 5% RH the hydrolysis lifetime increases to 810 milliseconds, while at 100% RH it decreases to 41 milliseconds.

The diffusion of PBr_3 vapor is very slow. The slow diffusion of the agent implies that its mixing will be primarily convective and subject to ventilation rates in the work area. Given the high hydrolysis rate even at low RH, PBr_3 would be expected to travel less than 1 cm from the liquid without reacting, under normal work ventilation conditions.

Based on the rapid reaction of liquid PBr_3 with water vapor, it is reasonable to assume that all of the released agent will be quickly converted to HBr and H_3PO_3 . H_3PO_3 melts at 74°C and is very soluble in water (300 grams

per 100 cc H_2O), so this material will not be airborne except as an aerosol. HBr , although also very soluble in water (221 grams per 100 cc water), is a gas at room temperature (20°C). A conservative assumption for accidental release is, therefore, that all of the PBr_3 is rapidly converted to gaseous HBr and aerosol H_3PO_3 , either on contact or by reaction in a zone less than a centimeter from the liquid.

Using this conservative model, the 10 cc PBr_3 cartridge (28.5 grams) that was tested in full scale engine nacelle tests should generate approximately 25.5 grams (0.315 moles or 7.05 liter atmospheres) of HBr . If all of the PBr_3 is converted to HBr and is uniformly distributed in a room 10x10x5 meters in size, the maximum concentration of HBr would be 14.1 ppm. The concentration is inversely proportional to the volume of the room; in a storage closet 2x2x2 meters in size, it would be 881 ppm. These concentrations are upper bounds since the gas will be immobilized as it freely dissolves in the moisture present on surfaces in the room. The rate of surface adsorption of HBr could be easily quantified by experiment if it is important for modeling smaller rooms. For direct comparison with the inhalation toxicology data, these concentrations can be expressed in mg/liter; 0.05mg/liter (51 mg/m^3) for the small room and 2.96 mg/liter ($2,961 \text{ mg/m}^3$) for the closet release.

Although there is no typical hangar size, dimensions of the hangars at Wright-Patterson Air Force Base are approximately 200x50x8 ft or 61.5x46.2x14.8 meters. The total volume of such a hangar is $42,051 \text{ m}^3$. If 25.5

grams of HBr is uniformly distributed in one of these hangars when it is empty, the maximum concentration would be 0.00061 mg/L (6.1×10^{-4} mg/L) or 0.61 μ g/L. This would be equal to 0.61 mg/m³ or 0.18 ppm or 180 ppb. This still is an upper bound because it assumes that all of the agent is sprayed over moist surfaces, through moist air and reacts 100% with the surface water and water vapor without any of it becoming dissolved in water.

SECTION III

RISK CHARACTERIZATION

For HBr exposure limits, National Institute for Occupational Safety and Health (NIOSH) set a ceiling limit of 10 mg/m^3 , Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) of 10 mg/m^3 as an 8-hr time weighted average (TWA) and American Conference of Governmental Industrial Hygienists (ACGIH) set a 10 mg/m^3 threshold limit value (TLV) as a ceiling. The maximal hangar concentration of 0.61 mg/m^3 would be an order of magnitude below the action level for these standards.

The NOAEL for the 28-day inhalation study was 0.1 mg/L for PBr_3 . Since PBr_3 reacts to form HBr, the maximum possible concentration of HBr present at the NOAEL was $9.0 \times 10^{-2} \text{ mg/L}$ or 90 mg/m^3 (Wolfe *et al.*, 1997). Therefore, the maximal concentration of HBr in the hangar after an accidental discharge of 10 cc PBr_3 would be two orders of magnitude lower than the concentration of HBr at the NOAEL for PBr_3 in the 28-day study.

The issue then becomes one of using either the standards for HBr or the NOAEL for PBr_3 as exposure limits. Until a standard for PBr_3 is developed and accepted, the standard for HBr will most likely be used by industrial hygienists. Even after a standard is developed for PBr_3 , exposure assessment will depend on the measurement of HBr since PBr_3 reacts so quickly with water vapor in the air. PBr_3 would not likely be used in anhydrous or dessicated areas in real world situations.

Due to the density of the PBr_3 and slow diffusion rate, it will not travel far after accidental discharge, allowing time for personnel to exit the area. Due to its reactivity, it will convert to HBr which should achieve high concentrations only in small rooms. In the 10x10x5 meter room, the maximum concentration of HBr possible (51 mg/m^3) is still lower (by almost one half) than the concentration of HBr present at the NOAEL for the 28-day PBr_3 study. There is still the issue of potential exposure to an individual at or very close to the point of release. Acid concentrations should to be measured or estimated for an accidental release scenario. The acid concentration could be determined for various heights and distances near the source in order to address this issue.

The primary hazard arises from direct contact with the skin. The use of this agent in occupied spaces is possible but may not be advisable in all cases. How PBr_3 is supplied, its placement in a system and industrial hygiene procedures can minimize the risks of its use.

SECTION IV

CONCLUSIONS

The reactivity of the agent with moisture and the solubility of the acid products in water make elevated airborne concentrations of PBr_3 and HBr extremely unlikely. The concentrations of HBr should be below the action level for exposure standards.

SECTION V

REFERENCES

1. Stavert, DM, Archuleta, DC, Mehr, MJ, and Lehnert, BE, 1991, Relative Acute Toxicities of Hydrogen Fluoride, Hydrogen Chloride and Hydrogen Bromide in Nose- and Pseudo-Mouth-Breathing Rats, Fund. Appl. Toxicol., 16:635-55.
2. RTECS, 1995a - National Technical Information Service, PB214-270.
3. HSDB, 1995a - BIOFAX Industrial Bio-Test Laboratories, Inc. 17-4/70.
4. HSDB, 1995b - Braker, W and Mossman, A, 1980, Matheson Gas Data Book 6th ed., 372.
5. ACGIH, 1991a, Documentation of the Threshold Limit Values and Biological Exposure Indices, 6th edition, 771-2 (Connecticut State Department of Health, 1955, Unpublished Data, Occupational Health Section, Hartford, CT.).
6. HSDB, 1995c - Clayton, GD, and Clayton, FE (eds.), 1981-82, Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology 3rd ed., John Wiley & Sons, New York, 2970.
7. Kraut, A. and R. Lilis. 1988. Chemical pneumonitis due to exposure to bromine compounds. *Chest* 94(1):208-210.
8. ManTech Environmental Technology, Inc. 1996. Final Report. Genotoxicity testing of phosphorus tribromide using Salmonella/microsome mutagenesis assay. ManTech Study No. 6053-200 (Task 3.2). March 15 - July 5, 1996.
9. Aqua Survey, Inc. 1996a. Final Report. Phosphorus tribromide - Acute effects on the fathead minnow, *Pimephales promelas*. Study #96-700220-110-4. July 19, 1996.

10. Aqua Survey, Inc. 1996b. Final Report. Phosphorus tribromide - Acute effects on the cladoceran, *Daphnia magna*. Study #96-300120-110-3. July 19, 1996.

11. Wolfe, RE, Feldmann, ML, Ellis, DH, Leahy, HF, Flemming, CD, Dodd, DE. 1997, Acute and Subchronic Toxicity Evaluations of the Halon Replacement Candidate Phosphorus Tribromide, AL/OE-TR-1997-0123, Wright-Patterson AFB, OH.